1992-09

United States Marine Corps Mobile Electric Power Optimization Model.

Samples, David W.

Monterey, California. Naval Postgraduate School

Unclassified

SECURITY CLASSIFICATION OF THIS PAGE

REPORT DOCUMENTATION PAGE

1a. REPORT SECURITY CLASSIFICATION Unclassified	1b. RESTRICTIVE MARKINGS
2a. SECURITY CLASSIFICATION AUTHORITY	3. DISTRIBUTION/AVAILABILITY OF REPORT Approved for public release; distribution is unlimited.
2b. DECLASSIFICATION/DOWNGRADING SCHEDULE	
4. PERFORMING ORGANIZATION REPORT NUMBER(S)	5. MONITORING ORGANIZATION REPORT NUMBER(S)
6a. NAME OF PERFORMING ORGANIZATION Naval Postgraduate School 6b. OFFICE SYMBOL *(If applicable)* 30	7a. NAME OF MONITORING ORGANIZATION Naval Postgraduate School
6c. ADDRESS *(City, State, and ZIP Code)* Monterey, CA 93943-5000	7b. ADDRESS *(City, State, and ZIP Code)* Monterey, CA 93943-5000
8a. NAME OF FUNDING/SPONSORING ORGANIZATION 8b. OFFICE SYMBOL *(If applicable)*	9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER
8c. ADDRESS *(City, State, and ZIP Code)*	10. SOURCE OF FUNDING NUMBERS Program Element No. / Project No. / Task No. / Work Unit Accession Number

11. TITLE *(Include Security Classification)*
MARINE CORPS MOBILE ELECTRIC POWER OPTIMIZATION MODEL

12. PERSONAL AUTHOR(S) Samples, David W.

13a. TYPE OF REPORT	13b. TIME COVERED	14. DATE OF REPORT *(year, month, day)*	15. PAGE COUNT
Master's Thesis	From To	September 1992	70

16. SUPPLEMENTARY NOTATION
The views expressed in this thesis are those of the author and do not reflect the official policy or position of the Department of Defense or the U.S. Government.

17. COSATI CODES			18. SUBJECT TERMS *(continue on reverse if necessary and identify by block number)*
FIELD	GROUP	SUBGROUP	Mobile Electric Power, Generators, Optimization, Linear Programming

19. ABSTRACT *(continue on reverse if necessary and identify by block number)*

This thesis develops a methodology that can be used to determine the type and quantity of mobile electric power generators necessary to meet current and future total Marine Corps electrical demand. This determination is a major part of the formal Marine Corps Mobile Electric Power Requirements Analysis. It is conducted in two steps. The first step involves application of the Army's Belvoir Generator Allocation Program (BGAP), a computer program that determines individual unit generator requirements, to individual Marine Corps units. The second step uses the BGAP results as input and determines the total force generator requirements and allocations over time using the Marine Corps Mobile Electric Power Optimization Model (MCMEPOM), a new model developed in this thesis. MCMEPOM is a non-consumptive demand, multiperiod linear programming model implemented with the General Algebraic Modeling System (GAMS).

20. DISTRIBUTION/AVAILABILITY OF ABSTRACT [X] UNCLASSIFIED/UNLIMITED [ ] SAME AS REPORT [ ] DTIC USERS	21. ABSTRACT SECURITY CLASSIFICATION Unclassified	
22a. NAME OF RESPONSIBLE INDIVIDUAL Kemple, William G. or Rosenthal, R.	22b. TELEPHONE *(Include Area code)* (408) 646-2795	22c. OFFICE SYMBOL OR-KE or OR-RL

DD FORM 1473, 84 MAR 83 APR edition may be used until exhausted. All other editions are obsolete

SECURITY CLASSIFICATION OF THIS PAGE
Unclassified

United States Marine Corps
Mobile Electric Power Optimization Model

by

David W. Samples
Captain, United States Marine Corps
B.S., United States Naval Academy, 1982

Submitted in partial fulfillment
of the requirements for the degree of

MASTER OF SCIENCE IN OPERATIONS RESEARCH

from the

NAVAL POSTGRADUATE SCHOOL
September 1992

ABSTRACT

This thesis develops a methodology that can be used to determine the type and quantity of mobile electric power generators necessary to meet current and future total Marine Corps electrical demand. This determination is a major part of the formal Marine Corps Mobile Electric Power Requirements Analysis. It is conducted in two steps. The first step involves application of the Army's Belvoir Generator Allocation Program (BGAP), a computer program that determines individual unit generator requirements, to individual Marine Corps units. The second step uses the BGAP results as input and determines the total force generator requirements and allocations over time using the Marine Corps Mobile Electric Power Optimization Model (MCMEPOM), a new model developed in this thesis. MCMEPOM is a non-consumptive demand, multiperiod linear programming model implemented with the General Algebraic Modeling System (GAMS).

THESIS DISCLAIMER

The reader is cautioned that computer programs developed in this research may not have been exercised for all cases of interest. While every effort has been made, within the time available, to ensure that the programs are free of computational and logic errors, they cannot be considered validated. Any application of these programs without additional verification is at the risk of the user.

TABLE OF CONTENTS

ACKNOWLEDGMENTS

I would like to recognize the following people for their contributions:

- Professor William G. Kemple for his enthusiasm and insight.
- Professor Richard E. Rosenthal for his optimization expertise and sacrifice of his own personal time.
- Professor Harold J. Larson for his availability.
- My parents, Jack and Carole Samples, for teaching me the value of hard work.
- My loving wife, Jean, and son, Sean, for their patience during this endeavor.
- My Lord and Saviour, Jesus Christ, for remaining true to His promises.

I. BACKGROUND AND STATEMENT OF THE PROBLEM

A. INTRODUCTION

The Studies Management Section of the Marine Corps Combat Development Command is responsible for the Marine Corps Studies System (MCSS). The purpose of MCSS is to:

> undertake studies and analyses to provide a greater understanding of issues and alternatives concerning Marine Corps organizations, tactics, doctrine, policies, force plans, strategies, procedures, intelligence, weapons selection and mix, systems, programs, or resources. These examinations provide conclusions and recommendations contributing to planning, programming, budgeting, decision making, and policy development. [Ref. 1]

The Mobile Electric Power (MEP) Requirements Analysis is one of the formal MCSS studies that will be conducted in fiscal year 1993. The specific objectives of the MEP Requirements Analysis will be to:

- Develop an operational power demand database for establishing the mobile electric power requirement.
- Design and develop a prototype MEP operational requirements model. [Ref. 1]

The purpose of this thesis is to develop the methodology that can be used to determine the type and quantity of mobile electric power generators necessary to meet current and future total Marine Corps electrical demand. This thesis addresses the active duty components of the Marine Corps, but the same methodology can be applied to the reserve, maritime preposition, and geo-prepositioned forces of the Marine Corps. The remainder of this chapter describes the current Marine Corps MEP program and three avenues that were pursued to gain insights into the problems that confront Marine Corps MEP planners.

B. CURRENT MARINE CORPS MEP PROGRAM

Marine Corps Order 11310.10B, *Mobile Electric Power Generators* [Ref. 2], provides guidelines for managing mobile electric power assets within the Marine Corps. The program it specifies has a four-fold purpose:

- To ensure that consistent, reliable, quality power is provided to those units that possess equipment requiring electricity.
- To maintain only the minimum number of generators in the inventory that are necessary to meet operational requirements.
- To ensure that the generators purchased for the Marine Corps come from the group of standard generators purchased by the Department of Defense.
- To ensure that new electrical equipment in the Marine Corps is compatible with existing generators.

To achieve this purpose, Marine Corps units that maintain generators in their inventories are categorized into four levels:

- Level 1 holder - Units with a daily need for generators to operate mission essential equipment. Level 1 holders maintain their own inventory of generators.

- Level 2 holder - One centralized unit each, within the division, wing, and force service support group (FSSG). The level 2 holders maintain generators for units in their respective major commands that do not have organic power assets. Level 2 holders also maintain an inventory of generators equal to 5% of the total number required by their major commands for use as backup and augmentation. The combat engineer battalion (CEB), marine wing support squadron (MWSS), and engineer support battalion (ESB) are level 2 holders for the division, wing, and FSSG, respectively.

- Level 3 holder - One unit per marine expeditionary force (MEF) that maintains backup and augmentation generators for the entire MEF. In addition to being designated a level 2 holder for the FSSG, the engineer support battalion of the FSSG is the level 3 holder for the MEF. The level 3 holder maintains a supply of generators equal to 10% of the total number required by the MEF.

- Level 4 holder - One unit per MEF designated as the operational readiness float (ORF). The maintenance battalion (MB) of the FSSG is designated as the level 4 holder for the MEF. A supply of generators equal to 5% of the total number required by the MEF is maintained as the ORF. [Ref. 2]

The Requirements Division of the Marine Corps Combat Development Center (MCCDC RD) at Quantico, Virginia is responsible for determining the Marine Corps MEP requirements. The Marine Corps System Command (MARCORSYSCOM) purchases and distributes MEP assets to meet new requirements and to replace old equipment. Figure 1 displays the current MEP structure.

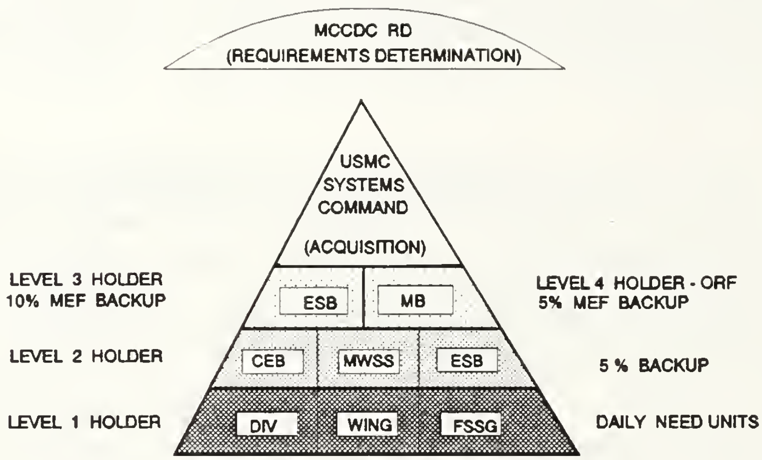

Figure 1. MEP Structure

Presently, no quantitative, standardized methodology exists to help the level holders determine the generators they need to accomplish their mission. Each level of the MEP structure in Figure 1 receives inputs from below, except level 1 holders. Because these inputs have inherent errors, requirements at each level are inflated.

The Marine Corps must have sufficient MEP assets to accomplish its mission, but it must not have too many. Due to downsizing, unit commanders do not have enough personnel in

MEP occupational specialties to maintain excess equipment. In addition, smaller operating and procurement budgets preclude purchasing and stockpiling unnecessary generators. Requirements determinations at all levels must be as accurate as possible.

C. PROBLEM IDENTIFICATION

Three avenues were explored to better understand the problems in the MEP program: a review of previous Marine Corps MEP studies, a field survey, and an examination of the Army's MEP program. These are discussed below.

1. Previous Marine Corps MEP Studies

In 1978, Headquarters Marine Corps reviewed all Marine Corps unit table of equipment (T/E) allowances for generators. This review resulted from a perceived proliferation in both the quantity and types of generators. As a result, new allowances were established. Marine Corps generators were restricted to the types in the standard family of generators displayed in Appendix A, and the quantity was reduced. But, standard methodology for determining the quantity and type of generators required by individual units was not established.

In 1987, the recurring MEP requirements problem resurfaced, and a mobile electric power study was initiated by the Marine Corps Development and Education Command. But, results of that study were not widely accepted. There are several reasons:

- Overstatement of MEP requirements due to double or inaccurate counting.

- Invalid assumption - total connected load for a unit based on every piece of equipment being operated at maximum power simultaneously.

- No effort made to determine how long equipment would be operated in combat conditions.

- Environmental conditions not taken into consideration, e.g., heaters and air conditioners assumed to operate at the same time.

- Unanswered questions - the study never answered the question of what would be the maximum power draw that could reasonably be expected for a unit. [Ref. 3]

In 1991, a Marine Corps Mission Area Analysis indicated that problems still existed in the MEP program, stating that "the MEP assets of the Marine Air-Ground Task Force (MAGTF) were insufficient to meet its energy requirements." [Ref. 4] The following shortcomings were identified:

- Under-utilization of generators.

- Level holders 2 and 3 had too many generators and too few maintenance personnel, resulting in generator deterioration.

- Some units did not have the correct allocation of generators to accomplish unit missions.

- Too many 400 hertz generators.

- Shortage of 60 hertz generators.

2. Field Survey Results

The second avenue of approach was to conduct interviews with Marine Corps units to help verify previously cited problems and to identify current trends. These interviews were also conducted because no specific MEP deficiencies had been recorded in the Marine Corps Lessons Learned Program at the MAGTF Warfighting Center, as a result of Marine Corps participation in Southwest Asia. The interviews would help capture a written record of valuable MEP experiences during actual combat conditions before that knowledge was lost. Twenty-nine units responded to the request for MEP points-of-contact and completed the questionnaires. Personal interviews were conducted with II MEF units at Camp Lejeune, MCAS New River, and MCAS Cherry Point, N.C. during the period 9 to 12 December 1991, and with I MEF units at MCAS Tustin, MCAS El Toro, MCAS Yuma, and Camp Pendleton during the period 4 to 7 February 1992. Fleet Marine Force (FMF) units in Hawaii and Okinawa responded by mailed questionnaires.

The questionnaire in Appendix B was used to interview 18 level 1 holders, and the one in Appendix C was used to interview 11 level 2 holders. Several results were common to level 1 and level 2 holders. Many did not know the level holder concept by name, but 100% knew how the program worked. Level 1 holders knew where to go for additional MEP support and level 2 holders knew who they supported. The most interesting result was that every unit in the survey used a 100 percent backup. The preferred scheme was to deploy the generators in pairs whenever possible. Table 1 summarizes important results from several of the survey questions.

TABLE 1. RESULTS FROM LEVEL 1 & 2 SURVEYS

Question	Level 1 Holder	Level 2 Holder
Unfamiliar with level holder concept	50%	30%
Lacked adequate personnel to perform MEP mission	45%	73%
Lacked enough generator assets to perform unit's assigned mission	33%	27%
Number of sites the unit could occupy had been limited by MEP assets	50%	36%
Knew unit's electrical power requirement	53%	27%
Agreed transportability was a problem	55%	27%

Figure 2 displays the percentage of units surveyed that operate their generators at various loads.

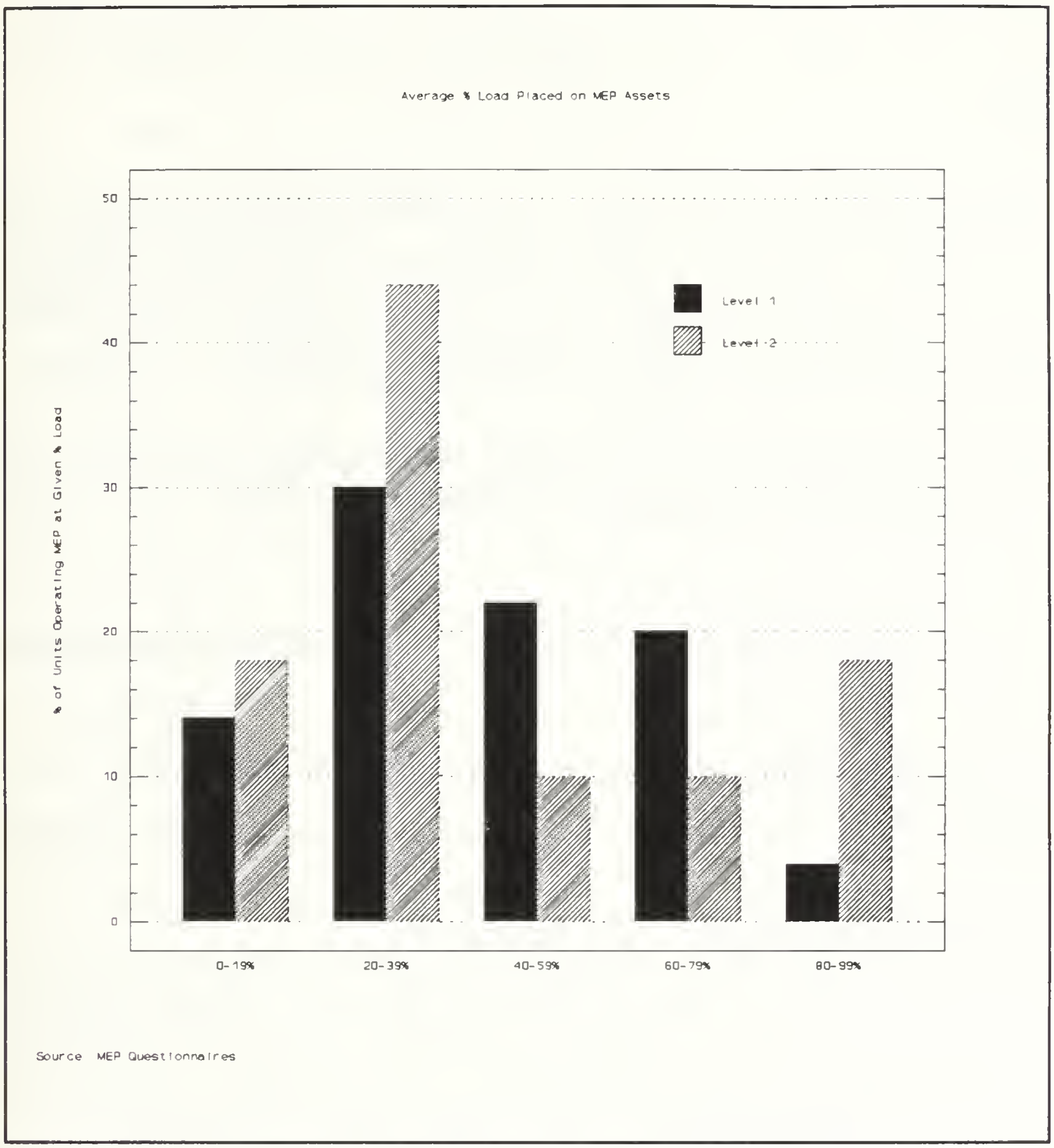

Figure 2. Average % Load Placed on MEP Assets

From Figure 2, 60% of the units surveyed operated their generators at an average load of less than 50%. This holds for both the level 1 and level 2 holders. Ideally, generators need to be loaded well above 50% for several reasons:

- Operating generators at low loads causes a problem known as "wetstacking." The diesel motor which powers the generator is not loaded enough for the motor's gaskets to form a complete seal, resulting in decreased performance.
- Using larger than necessary generators results in increased fuel demand.
- Increased weight of larger generators and higher fuel demand leads to an increased demand for heavier transportation assets.

The deficiencies listed in [Ref. 4] were confirmed in the survey results. In addition, the following list identifies deficiencies common to three or more units surveyed that were not identified in previous Marine Corps studies:

- Excessive noise of MEP generators.
- Lack of a paralleling capability for MEP-003 generators.
- Fuel pump shaft shearing problems/alternate fuel problem (14 shafts cited).
- Offloading problems with Maritime Preposition Force (MPF) gear.
- Shortage of forklifts to lift MEP assets.
- Inadequate number of trailers.
- For units with adequate trailers, lack of prime movers.
- Load banks needed.

- Too many generators to maintain in peacetime - units have put generators into local storage.
- Generators returned from Southwest Asia were mechanically abused.

Many of the problems cited previously and confirmed during the field interviews were technical problems with particular pieces of equipment. However, a large number of recurring problems are symptomatic of the lack of a standardized methodology for determining a unit's actual power requirement. Changes in equipment, personnel, and individual unit missions make the allocation of MEP assets a dynamic process, but thus far it has been treated as static. Because of this static approach, a complete reevaluation of MEP requirements is necessary approximately every five years.

3. Army MEP Problems

The third area of study was the Army MEP Program. The Army is responsible for the acquisition of all MEP generators within the Department of Defense. The Marine Corps Program Manager for Mobile Electric Power (PM MEP) works through the Department of Defense PM MEP, an Army command, to purchase generators. As Table 2 illustrates, the Marine Corps MEP program is small compared to the Army program.

TABLE 2. ARMY, MARINE CORPS MEP COMPARISON

BRANCH	Diff. Types of MEP	Total # MEP	Annual Budget	% of Total DOD MEP Assets
ARMY	> 40	138,280	$ 42-55 million	85%
USMC	< 20	<10,000	$ 2.5 million	4%

In 1987, while the Marine Corps Mobile Electric Power Study was being conducted, the Army was also trying to assess its MEP problem. Several independent studies were conducted. In one, the BDM Corporation identified the following problem trends in the Army MEP program:

- Growth in the demand for power that was not purely a result of the increase in the tactical electric power requirements of weapons systems and command and control.

- Increases in the number of generators assigned to a unit because of a tendency toward conservatism in the US Army Training and Doctrine Command (TRADOC) Tables of Organization and Equipment (TOE).

- A proliferation of generators due to commanders' desires to protect against generator failure, resulting in overstatement of generator requirements. [Ref. 5]

Data was collected on generator use during Army field training exercises from 1 October 1987 to 31 March 1988 as part of the Tactical Assessment of Power (TAP) Program conducted by the Belvoir Research, Development and Engineering

Center (Belvoir RD&E). MEP deficiencies noted during these exercises were:

- Mobility, noise, reliability, and maintainability problems.
- Low utilization rate - only 36% of the 578 generators deployed to the field during the exercises were used.
- Low loading rate - the average percentage load placed on those generators actually used was only 25%. [Ref. 6]

A power sources study was also conducted as part of an Army Training and Doctrine Command Mission Area Analysis (TRADOC MAA). The following list of deficiencies was noted:

- Power sources design incompatible with duration of current operational requirements.
- Vulnerability to detection due to power sources noise and IR signatures.
- Reduced unit mobility due to heavy generator trailers.
- Reduced availability and inadequate reliability of power sources due to poor maintenance practices.
- Significant electrical power required by environmental control equipment.
- Excessive dependence on load banks; lack of load banks at maintenance elements.
- Need to review long-term power generator proponency assignment.
- Inadequate means to allocate power sources to supported systems.
- Inadequate acquisition planning to meet new system generator requirements and readiness requirements.
- Lack of qualified and trained power sources maintenance personnel at unit level.

- Excessive reliance on commercial power sources.

- Insufficient fuel capacity to meet mission duration requirements.

- Excessive use of both precise and utility power generators (within a unit) which reduces operational flexibility and increases logistical burdens.

- Inadequate nuclear survivability. [Ref. 7]

It is clear that Marine Corps and Army MEP deficiencies are similar. Compared to the Army, the numerical size of the Marine Corps MEP problem is much smaller, but the deficiencies are similar and just as troublesome. As a result of the Army MEP studies, the Belvoir Generator Allocation Program (BGAP) was developed. The purpose of BGAP was to:

> provide a quantitative method of analyzing the electric power requirements of tactical units and the appropriate electric generator(s) necessary to provide the required power. [Ref. 8]

Recall that the 1987 Marine Corps MEP study incorrectly addressed the way electrical equipment would be operated in combat and what the subsequent power requirements would be [Ref. 3]. The approach behind the Army studies differed greatly from that taken by the Marine Corps. BGAP considered the way each unit would be task organized in combat and how it would tactically use its equipment. In an attempt to determine a current baseline for generators, the Marine Corps MEP Requirements Analysis will:

> identify and consider all operational variables as they apply to current contingencies (i.e., climate, altitude, host nation support, tactical dispersion, line loss, back-ups, augmentation, partial loading, etc.). Identify requirements by Table of Equipment (T/E) ... the approach and model used must be structured to accept changing force structures and Tables of Equipment over a period of time. [Ref. 1]

BGAP has been used successfully by the Army to handle the variables listed above. The BGAP methodology can be applied to Marine Corps force structure and equipment. It is included in the methodology developed in this thesis.

D. APPROACH

The Marine Corps MEP requirements problem is to determine the type and quantity of MEP generators necessary to meet current and future total Marine corps electrical demand. This thesis develops a two-step method for solving this problem. The first step involves applying BGAP to Marine Corps units and equipment. The BGAP process is described in Chapter II. The second step uses the results from individual unit BGAP runs along with force structure and cost and budgeting information as input, and employs the Marine Corps Mobile Electric Power Optimization Model (MCMEPOM) to determine an optimal generator allocation for the entire Marine Corps over time. MCMEPOM is described in Chapter III.

The remainder of the thesis is organized as follows: Chapter IV describes data sources, collection, and organization for using MCMEPOM, and Chapter V gives conclusions, observations, and recommendations. Appendix A lists the current Marine Corps standard MEP generators, Appendices B and C are the questionnaires that were used to interview level 1 and 2 MEP holders, and Appendix D is the computer code for MCMEPOM.

II. BELVOIR GENERATOR ALLOCATION PROGRAM (BGAP)

A. BGAP CONCEPT

BGAP determines the generator requirements for individual units based on the way they will be organized and equipped for combat. The BGAP program uses a set of databases that have appropriate information on generators and power consuming equipment. Figure 3 displays the process used to analyze a unit's power requirements. It is explained in the paragraphs that follow. Footnotes highlight similarities and differences with the Marine Corps.

POWER ANALYSIS PROCESS
SCENARIO DEFINITION
EQUIPMENT CLASSIFICATION
TOE SELECTION
TACTICAL GROUP CONVERSION
TACTICAL GROUP REFINEMENT
POWER ANALYSIS
GENERATOR SELECTION

Figure 3. BGAP Process

1. Scenario Definition

During scenario definition, the user selects an area of the world where the equipment will be operated. Environmental temperature ranges are then obtained from an internal database because temperature extremes downgrade generator performance. Operating altitude is also selected and generator performance downgraded accordingly.

2. Equipment Classification

Equipment is classified into five categories based on criticality, expected number of hours operation each day, and the confidence level of being able to run all the equipment in that category at the same time. Figure 4 displays the default values for these categories.

Equip Class	Category	Time (hrs/day)	Confidence (%)
1	Mission Essential-Continuous	24.0	100
2	Mission Essential-Intermit.	14.4	95.0
3	Environmental Control	24.0	100
4	Maintenance	4.8	50.0
5	Convenience	1.2	15.0

Figure 4. Equipment Classification Defaults

3. Table of Organization and Equipment Selection

The Army Table of Organization and Equipment (TOE) gives the personnel and equipment within a unit.[1] Once a unit is selected for analysis, that unit's TOE can be downloaded via modem from the U.S. Army Training and Doctrine Command Center (TRADOC) into the BGAP program. TOEs are administrative groupings, so BGAP will list several groups in each unit, such as the administration (S-1) section, intelligence (S-2), etc., and the associated equipment.

4. Tactical Group Conversion

The user groups the administrative sections and equipment in the TOE into tactical groupings. A tactical grouping is defined as any group of personnel or equipment which obtains its power from a single generator source. The distance from the equipment to the generator is 100 meters or less. Equipment outside a radius of 100 meters will exhibit excessive voltage loss.[2] This distance assumption was confirmed by experience in operational exercises [Ref. 6].

---

[1]. This differs from the Marine Corps, which operates under a separate Table of Organization (T/O) and Table of Equipment (T/E) for each unit.

[2]. During interviews at the Marine Corps Engineer School at Camp Lejeune, N.C., in December of 1991, the 100 meter assumption was verfied for Marine Corps units.

5. Tactical Group Refinement

Once the basic tactical group is established, further refinements can be made. Specific items can be modified, added, or deleted from a tactical group.

6. Power Requirements Analysis

With the tactical groups established within a unit, a power requirements analysis is conducted separately for each group. Because the equipment in classifications 1 and 3 operates continuously, the total power required for that equipment is the sum of the power requirements for each piece of equipment. The remaining three categories operate intermittently during the day. The power required for those classes is calculated using an approach similar to that employed by civilian electrical utilities to calculate power required over a changing demand schedule during the day.

7. Generator Selection

The BGAP program will display up to ten generators that fulfill the total power requirement for a given tactical group. The user can then select the most appropriate generator from the list.

B. MARINE CORPS USE

The BGAP program is maintained by the U.S. Army Belvoir Research, Development and Engineering Center at Fort Belvoir, Virginia. The program databases are updated annually.

BGAP was demonstrated to the Marine Corps Program Manager for Mobile Electric Power at the Marine Corps Systems Command in the fall of 1991. Subsequent conversations with the BGAP program manager at the U.S. Army Belvoir Research, Development and Engineering Center indicated that with a memorandum of understanding, the Marine Corps would be able to use the BGAP program. Use would be free, but funding would be required for initial inclusion of Marine Corps equipment in the databases and for periodic maintenance. BGAP would provide a standardized method for determining generator allowances based on a unit's organization, equipment, and mission. In addition, new generator requirements could be computed when changes in unit organization, equipment, or mission occurred by reapplying the BGAP program. This alone is a significant improvement over current methods. To determine the generators required to power a given group of equipment, utilities personnel currently have to develop an electrical load plan by hand. In effect, BGAP has automated that process.

The BGAP output for each type of unit in the Marine Corps, coupled with the planned structure of the Marine Corps, and cost and budgeting information provides the input needed by the MCMEPOM to determine total Marine Corps generator requirements over time. MCMEPOM is described in the following chapter.

III. MCMEPOM

A. LINEAR PROGRAMMING

The Marine Corps Mobile Electric Power Optimization Model (MCMEPOM), developed in this thesis, is a linear programming (LP) model written in the GAMS language (described below). Linear programming is a mathematical procedure often used to determine optimal allocation of scarce resources. An LP model is characterized by either maximizing or minimizing an objective function subject to various constraining functions where all functions involved are linear. One of the most important uses of LP is multiperiod planning.

MCMEPOM is a non-consumptive demand, multiperiod planning model. It is non-consumptive because the generators used to meet demand within a unit are not consumed in the process. It is multiperiod because it determines the optimal allocation of generators over a given time period. Through linear programming, MCMEPOM aggregates the BGAP recommendations for individual units into an optimal full force generator requirement and allocation over time.

B. GENERAL ALGEBRAIC MODELING SYSTEM (GAMS)

All linear programming models contain an objective function and constraints. GAMS allows the model to be represented in a concise, mathematical format. GAMS is well suited for the complexity of a large scale Marine Corps MEP requirements model. GAMS was specifically developed to:

- Provide a high-level language for the compact representation of large and complex models.
- Allow changes to be made in model specifications simply and safely.
- Allow unambiguous statements of algebraic relationships.
- Permit model descriptions that are independent of solution algorithms. [Ref. 9]

C. MODEL FORMULATION

The GAMS code for MCMEPOM is listed in Appendix D. The overall objective of MCMEPOM is to provide a best fit of Marine Corps generator assets for the entire active duty Marine Corps structure based on individual unit requirements and planned procurement budgets. The planning period covered is from the year 1992 through 2000. Individual unit generator inventories are adjusted throughout the planning period to give the best fit at the end of each year for the entire force. Generator inventory within a unit can be adjusted by:

- Purchasing new generators.
- Shipping generators to or from the depot.
- Stockpiling additional generators.
- Adjusting an elastic variable if a unit's inventory is under the BGAP recommendation.

1. Indices

Sets are the basic building blocks in a GAMS model. The following sets are used in MCMEPOM:

- T - Fiscal year acquisition period.
- I - Marine Corps units considered in the model. Unit identification numbers coincide with T/E numbers whenever possible. Set II is an "alias" of set I.
- M - Type of standard DOD MEP generator as listed in Appendix A. Set MM is an "alias" of set M.
- P - Penalty for deviations from the number of generators recommended by the BGAP program. Penalty is incurred when inventory is either above or below the recommended amount.

2. Decision Variables

The following decision variables are used in MCMEPOM:

- X(I,M,T) — Total number of new type M generators purchased for unit I in period T.
- Y(I,M,MM,T) — Total number of type MM generators filling demand for type M generators in a unit's inventory. This allows larger generators to substitute for smaller.
- TRANS(I,II,M,T) — Total number of generators shipped to or from the depot of generator type M in period T.
- STOCKPILE(I,M,T) — Total number of type M generators unit I may possess in inventory in period T over the amount recommended by the BGAP program. A threshold limit is set for each unit.
- EDN(I,M,T) — An elastic variable for unit inventory below the amount recommended by the BGAP program.

3. Given Data

The following constants are used in MCMEPOM:

- WTSUB — Weight of the penalty for substituting generators.
- WTXFER — Weight of the penalty for transferring generators to or from the DEPOT.
- WTUP — Weight of the penalty for inventory over the amount recommended by the BGAP program.
- WTDOWN — Weight of the penalty for inventory under the amount recommended by the BGAP program.
- LEAD — Number of years that generators may be pre-purchased or stockpiled for a unit.

Parameter data is indexed by one of the sets given previously. The following parameter data is used in MCMEPOM:

- THRESHOLD(I) — Maximum permissible excess inventory in % over the BGAP recommendation for unit I.
- RETIRE(M) — Percentage of type M generators retired each year.
- BUDGET(T) — Amount of money available in period T for new generator purchase.
- XFERCOST(M) — Cost to transfer a type M generator to or from the DEPOT.

Tabular data is indexed by two or more of the sets given above. The following data is used in MCMEPOM:

- FORCES(I,T) — Number of units of type I in period T.
- BGAP(I,M,T) — Number of type M generators recommended by BGAP in period T for a type I unit.

- DEM(I,M,T) — Total number of type M generators needed for all type I units in period T. DEM(I,M,T) = BGAP(I,M,T) x FORCES(I,T).

- MAXDEM(M,T) — Largest unit demand of type M generator in period T.

- UPPEN(I,M,T) — Penalty for unit I having overage of type M generators in period T.

- DNPEN(I,M,T) — Penalty for unit I having shortage of type M generators in period T.

- NEWCOST(M,T) — Cost to purchase a new type M generator in period T in adjusted dollars.

- SUBCOST(M,MM) — Cost to substitute a type MM generator for a type M generator. Ex: If a 10 kW generator substitutes for a 3 kW, cost is 7 kW (equal to kW forfeited).

- PENALTY(M,P) — Type M generator up or down penalty Penalty is equal to the generator kW rating.

- SUBST(M,MM) — Identifier that indicates if a type MM generator can substitute for a type M generator. Only larger generators of the same frequency may substitute for smaller.

- INITINV(I,M) — Initial inventory of type M generators held by unit I.

4. Constraints

Equation (3.1) is the balance constraint for the DEPOT. The constraint ensures that the uses of generators is equal to the sources of generators for the DEPOT ∀ I, M, T.

$$\begin{aligned}
&\sum_{I} TRANS(I, DEPOT, M, T) \\
&= \\
&INITINV(I, M, T) + \\
&\sum_{I} TRANS(DEPOT, I, M, T)
\end{aligned} \tag{3.1}$$

Equation (3.2) is the balance constraint for a non-depot unit. The constraint ensures that the uses of generators within a unit is equal to the sources of generators ∀ I, M, T.

$$\begin{aligned}
&TRANS(I, DEPOT, M, T) \\
&+ \sum_{MM} Y(I, MM, M, T) \\
&+ STOCKPILE(I, M, T) \\
&= \\
&INITINV(I, M, T) \\
&+ X(I, M, T) \\
&+ TRANS(DEPOT, I, M, T) \\
&+ (1-RETPCT(M)) * \sum_{MM} Y(I, MM, M, T-1) \\
&+ (1-.5(RETPCT(M)) * STOCKPILE(I, M, T-1)
\end{aligned} \tag{3.2}$$

Equation (3.3) ensures that all generators held in inventory plus an elastic variable for any shortage must equal demand ∀ I, M, T.

$$\sum_{MM} Y(I,M,MM,T) + EDN(I,M,T) = DEMAND(I,M,T) \tag{3.3}$$

Equation (3.4) ensures that the cost of all generators purchased must be less than or equal to the amount available in the budget ∀ T.

$$\sum_{I}\sum_{M} [X(I,M,T) * NEWCOST(M,T) * FORCES(I,T)] \leq BUDGET(T) \tag{3.4}$$

5. Objective Function

The goal of the objective function, equation (3.5), is to minimize the total Marine Corps deviation based on unit recommendations from BGAP. Penalties are incurred whenever larger generators are used in place of smaller ones, when overages or shortages exist, and whenever generators are shipped to and from the depot. In algebraic notation, the objective function is to minimize:

$$\sum_{I}\sum_{MM}\sum_{M}\sum_{T} SUBCOST(M,MM) * Y(I,MM,M,T)$$

$$+\sum_{I}\sum_{M}\sum_{T} XFERCOST(M) \quad * TRANS(I,DEPOT,M,T)$$

$$+\sum_{I}\sum_{M}\sum_{T} XFERCOST(M) \quad * TRANS(DEPOT,I,M,T) \qquad (3.5)$$

$$+\sum_{I}\sum_{M}\sum_{T} UPPEN(I,M,T) \quad * STOCKPILE(I,M,T)$$

$$+\sum_{I}\sum_{M}\sum_{T} DNPEN(I,M,T) \quad * EDN(I,M,T)]$$

D. ASSUMPTIONS

1. Depot

The original intent of the model was to give each unit the capability of shipping generators to any other unit. The number of variables entailed would make the model unsolvable, however, so a simplifying assumption is made that all shipments pass through a unit called DEPOT. DEPOT corresponds to the Marine Corps logistics bases at Albany, Georgia or Barstow, California. Penalties for shipments are based solely on the size of the generator (in kW), not on the distance from the unit to the DEPOT.

2. Up and Down Inventory Penalties

Units with a small BGAP demand for generators are penalized more heavily for deviations from the recommendation. For example, a unit that needs 10 generators but has 11 is 10% over inventory. A unit that needs 100 generators but has 101 is only 1% over inventory. Heavier penalties are also incurred early in the planning period to bring inventories into line with the BGAP recommendations as early as possible. Equation (3.6) and (3.7) display the formulas used to calculate the overage and shortage penalties, respectively.

$$UPPEN(I,M,T) = PENALTY(M,''UP'') * .99^{(ORD(T)-1)} * e^{-\left(\frac{DEM(I,M,T)}{MAXDEM(M,T)}\right)} \quad (3.6)$$

$$DNPEN(I,M,T) = PENALTY(M,''DWN'') * .99^{(ORD(T)-1)} * e^{-\left(\frac{DEM(I,M,T)}{MAXDEM(M,T)}\right)} \quad (3.7)$$

3. Stockpiling

Units are allowed to maintain generators above the amount recommended by the BGAP program up to a threshold limit. Below the threshold limit, a unit commander can put extra generators into a local storage program. Above the threshold limit, the overage would strain the manpower and maintenance capabilities of the unit. Therefore, generators above the threshold limit are shipped to the DEPOT.

4. Totals

Numbers of generators are always given for aggregated units. For example, if 5 units of type I exist, and each unit has 2 generators, the total number reported for type I units is 10.

E. MODEL RESULTS

The model was run separately for the Marine division, wing, FSSG, and command element inputs on a mainframe computer. The GAMS/XA solver took approximately two minutes to solve each separate run. Using a 486 PC running at 25 megahertz with the XA solver, each run solved in approximately 4 minutes.

The model was also run on an Amdahl model 5995-700A mainframe computer with the entire Marine Corps structure used as input. The GAMS/XA solver took less than 20 minutes to yield a solution to a problem with over 26,000 variables. Two separate reports are generated by the model to display the results.

IV. MODEL DATA PROCESSING

The Marine Corps force structure is going through dynamic, drastic changes. Every effort was made to get the best data available, but the future is uncertain. MCMEPOM has been designed to easily adapt to changes in force structure.

A. SOURCES OF DATA

The following data sources were used in MCMEPOM:

- USMC tables of equipment were provided by Installations and Logistics at Clarendon, Virginia.
- USMC tables of organization were provided by the Manpower section at Headquarters Marine Corps.
- Future Marine Corps force structure was derived from the Force Structure Plan (FSPG) dated 15 August 1991 and inputs from the division, wing, FSSG, and command element/SRIG proponents at the MAGTF Warfighting Center, Quantico, Virginia.
- BGAP data for the current model run is artificial because the BGAP program was not available at the time of this writing. The BGAP program is currently undergoing upgrade by the SAIC corporation. Marine Corps equipment would have to be incorporated into BGAP databases before USMC unit MEP requirements could be computed.
- Current mobile electric power inventories were obtained from Marine Corps Logistics Base (MCLB) Albany, Georgia.
- MEP retirement percentages were obtained from MCLB Albany. Because of the small numbers of generators retired from service as compared to the total number available, retirement percentage was set to zero for each type of generator. Setting the retirement percentages to zero also helped the GAMS solver give integer valued solutions in most cases.

- Generator purchase cost and budget data were obtained from the Program Manager for Mobile Electric Power at the Marine Corps Systems Command. Cost and budget data are computed as then year dollars. An average inflation factor of 4% was used with 1992 as the base year.

B. MODEL PREPROCESSING METHODOLOGY

The BGAP program provides a standardized methodology for determining an individual unit's MEP requirements, but it does not address the quantity and types of units that will make up the future Marine Corps. The division, wing, FSSG, and command element portions of the Marine Corps Force Structure Plan were analyzed to determine the future force structure of each major component of the Marine Corps. Special emphasis was placed on how that force structure will affect mobile electric power requirements.

C. SPREADSHEET DATA INTERFACE

GAMS provides a concise way of representing a linear programming model, but its data handling procedures are difficult for one not familiar with the language. Since most computer users are familiar with spreadsheet programs, Lotus 1-2-3 was used to simplify data input and alleviate future problems. Lotus spreadsheets were developed for the division, wing, FSSG, and command element. These spreadsheets detail the entire Marine Corps active duty force structure by individual unit. Changes to individual units and subsequent aggregation into higher commands are accounted for. As new information becomes available on force structure or results from a BGAP run for an individual unit become available, the spreadsheets can be easily updated. Once all changes are complete, the spreadsheets are used as input to MCMEPOM.

V. CONCLUSIONS, OBSERVATIONS, AND RECOMMENDATIONS

A. CONCLUSIONS

The methodology presented in this thesis gives MEP planners a dynamic tool for determining Marine Corps MEP requirements. BGAP provides a quantitative and reproducible method for individual units to determine and understand their MEP needs. The individual unit BGAP results, force structure changes, and cost and budgeting information provide the input the Marine Corps Mobile Electric Power Optimization Model uses to determine the best fit of MEP assets over the whole active duty Marine Corps structure.

The Army has invested over one million dollars developing the BGAP program over the last five years. This amount represents half of the annual Marine Corps budget for new MEP purchase. The BGAP methodology has been verified by the Army. Its application to individual units, combined with MCMEPOM, should help to alleviate many of the problems within the Marine Corps MEP program.

B. OBSERVATIONS

Early in the problem identification stage of this thesis, several facts became evident. First, the long range planning documents which direct future Marine Corps structure, planning, doctrine, training, and equipment acquisition do not specifically address mobile electric power. Silence on the specifics does not negate the importance of and requirement for mobile electric power in the future, however. Mobile electric power requirements will exist as long as the Marine Corps fields equipment which requires electricity.

The Marine Corps should plan to meet its electrical demand with internal assets. The future Marine Corps will be a light to medium enabling force which will train and equip itself to fight over the whole spectrum of low, mid, and high intensity conflict. The highest probability of conflict will occur in the low to mid range. These are the areas in which the Marine Corps will concentrate its efforts. One of the assumptions of mid-intensity conflict is that it will occur in an austere and remote operational environment. Host nation electrical support would be advantageous in this type of environment, but the Marine Corps cannot count on this additional support. For example, in the low intensity conflict arena, humanitarian assistance operations are emphasized. After a typhoon struck Bangladesh in April of 1991, that country's infrastructure was severely damaged. Mobile electric power generators were required as part of the relief provided by Marine Corps units. [Ref. 10]

While the need for mobile electric power assets is certain in the future, the exact type of generators is not specified. The guiding principle in the development of future generators is that they must contribute to the expeditionary nature of the Marine Corps. [Ref. 11] states:

> the entire Marine force will be more expeditionary -- lighter, more mobile, and more capable of conducting a wide range of military operations across the whole spectrum of conflict.

Future mobile electric power generators must possess the following attributes:

- Technologically capable - the Marine Corps will exploit affordable new technology. Present generators will be replaced with the new family of tactical quiet generators (TQG) during future acquisition. TQG offers a lower infrared signature and quieter operating characteristics than present generators.
- Maneuverable - success on the battlefield will require highly mobile and self-supporting forces. Power sources will be more efficient and less of a logistics burden.
- Survivable - to achieve survivability and maintain operability, a combination of mobility, agility, hardness, cover, deception, and training will be required. [Ref. 11]

While [Ref. 12] does not address MEP specifically, it does outline a concept for aviation modernization which is equally applicable to future mobile electric power. "Aviation modernization investments will emphasize increased survivability, high reliability and maintainability for austere environments, and greater flexibility in deployment and employment." These guiding principles, combined with an emphasis on expeditionary capability and mobility, give focus to future generator development and procurement.

C. RECOMMENDATIONS

The Marine Corps is encountering the same problems that the Army faced five years ago. Since the Army is the lead service in DOD for mobile electric power, valuable lessons can be learned from their experiences. The following actions are recommended:

- Contact the Belvoir Research, Development, and Engineering Center to draft the memorandum of understanding between the Marine Corps and Army for BGAP's use by the Marine Corps.
- Provide funding for initial inclusion and periodic maintenance of Marine Corps equipment in the BGAP databases.
- Provide the Army with the use of the optimizer in their MEP program.
- Make liaison with Army TRADOC for information on TOE interface with BGAP and other BGAP data collection lessons learned.

D. FUTURE AREAS OF RESEARCH

The following actions would be beneficial to the future functioning of MCMEPOM:

- Automate the procedures for collecting and including data into MCMEPOM.
- Provide instruction to the Engineer School at Camp Lejeune, N.C. on the functioning of BGAP so that future utilities personnel become familiar with the program.
- Apply MCMEPOM to the trailer and personnel requirements of the Marine Corps since those two entities are also non-consumptive.

LIST OF REFERENCES

1. Commanding General, Marine Corps Combat Development Center (Code WF13F), *Statement of Work for the Mobile Electric Power (MEP) Requirements Analysis Study*, Quantico, VA., January 1992.

2. Commandant of the Marine Corps (Code LME), *Marine Corps Order 11310.10B, Mobile Electric Power Generators*, HQMC, Washington, D.C., January 1981.

3. Commanding General, Marine Corps Development and Education Command, *Comments on Mobile Electric Power (MEP) Study Draft Final Report (DFR)*, Quantico, VA., July 1987.

4. Commanding General, Marine Corps Combat Development Center, *Marine Corps Mission Area Analysis MA-44*, MCCDC, Quantico, Virginia, May 1991.

5. BDM Corporation, *An Analysis of Future US Army Tactical Electric Power Requirements*, McLean, VA., March 1987.

6. COBRO Corporation, *Tactical Assessment of Power (TAP) Program Semi-Annual Report*, Wheaton, MD., February 1989.

7. U.S. Army Engineer School, *Power Sources Study, Volume V.*, TRADOC ACN 70608, 1988.

8. Harrington, P., Morsch, B., and Jefferson, T., *Implementation Plan for Electric Power Databases*, SAIC Corporation, McLean, VA., January 1989.

9. Brooke, A., Kendrick, D., Meeraus, A., *GAMS: A User's Guide*, The Scientific Press, 1988.

10. Commandant of the Marine Corps (Code WF-10), *Marine Air-Ground Task Force Master Plan (MMP) 1992-2002*, HQMC, Washington, D.C., June 1991.

11. Commandant of the Marine Corps (Code WF 10), *Marine Corps Long-Range Plan (MLRP) 2000-2010*, HQMC, Washington, D.C., June 1991.

12. Commandant of the Marine Corps, *United States Marine Corps 1992: Concepts and Issues*, HQMC, Washington, D.C., 1992.

APPENDIX A

MARINE CORPS STANDARD MOBILE ELECTRIC POWER GENERATORS

TAMCN	Model No.	Kw Rating	Frequency	Classification
B0730	MEP-016	3 Kw	60 Hz	Utility
B0891	MEP-003	10 Kw	60 Hz	Utility
B0921	MEP-112	10 Kw	400 Hz	Utility
B0953	MEP-115	30 Kw	60 Hz	Utility
B0971	MEP-114	30 Kw	400 Hz	Precise
B1016	MEP-115	60 Kw	400 Hz	Precise
B1021	MEP-006	60 Kw	60 Hz	Utility
B1045	MEP-007	100 Kw	60 Hz	Utility

APPENDIX B

MOBILE ELECTRIC POWER STUDY DATA COLLECTION

Level I Holder Survey

The following survey is part of the Mobile Electric Power (MEP) study currently being conducted by the Marine Corps. Your answers to these questions will be analyzed to help the Marine Corps determine its mobile electric power requirements for the future. At any time, please feel free to write in any additional comments appropriate for a given question.

Privacy Act Information

The data collected with this questionnaire will be used for research purposes only. Personal information will be used for administrative and statistical control purposes only. Full confidentiality of your responses will be maintained in the processing of the data. Disclosure of information is voluntary. Not providing information, however, will mean your views will not be included in the analysis of survey results.

Administrative Information (Please Print)

NAME ____

RANK ________________

MOS ________________

UNIT ____

AUTOVON ____

Level I Holder Survey

1. Are you familiar with the Level Holder Concept for Mobile Electric power?

_____ Yes

_____ No

2. Does your unit have an SOP for Mobile Electric Power or other instructional guidelines?

_____ Yes

_____ No

3. Included with this survey is a T/E displaying your unit's power consuming equipment based on the most current information in the LMIS system. To the best of your knowledge, is this T/E complete?

_____ Yes

_____ No: Please make corrections or additions on the T/E

4. As a Level I MEP holder, your unit has a daily requirement for generator power. How many generators does your unit hold? (Fill in appropriate number in spaces below: numbers are actual on-hand generators vice T/O)

_____ 3Kw/60Hz   _____ 10Kw/60Hz   _____ 10Kw/400Hz

_____ 30Kw/60Hz   _____ 30Kw/400Hz   _____ 60Kw/60Hz

_____ 60Kw/400Hz   _____ 100Kw/60Hz

5. Does the number of above generators adequately support your unit's mission?

_____ Yes

_____ No. Comments:_________________________________

____

6. How many of the following types of personnel does your unit have?

_____ Licensed generator operators

_____ Electricians (MOS 1141)

_____ Electrical Equipment Repairman (MOS 1142)

7. Are the above personnel adequate to support continuous operations of your MEP assets?

_____ Yes

_____ No. Comments: ______________________________

____

8. When your unit deploys, how many sites will the unit divide into on average? (Define a site to be a collection of equipment and personnel getting their power from a single generator)

No. of sites _____

9. Has the number of sites ever been limited by your power assets?

_____ Yes

_____ No

10. How do you determine the type of generator you need for a given site?

____

____

____

11. What guidelines do you use to determine the type and quantity of generators to have as backup?

____

12. Is this backup adequate?

_____ Yes

_____ No. Comments:_______________________________________

____

13. On your unit's T/E, annotate next to a given piece of power consuming equipment what you consider it's power requirement to be. Use the following abbreviations;

MC: **Mission Essential Continuous Power. Equipment will operate 24 hours continously and requires 100% confidence that power will be available.**

MI: **Mission Essential Intermittent Power. Equipment will operate up to an including 14.4 hours in a 24 hour period and requires 95% confidence that power will be available.**

DH: **Deferable Power (High Activity). Equipment will operate up to 9.6 hours in a 24 hour period and requires 75% confidence that power will be available.**

DM: **Deferable Power (Medium Activity). Equipment will operate up to 4 hours in a 24 hour period and requires 50% confidence that power will be available.**

DL: **Deferable Power (Low Activity). Equipment will operate up to 1.2 hours in a 24 hour period and requires only 5% confidence that power will be available.**

B: **Battery powered**

V: **Powered by a vehicle power source**

X: **External or other power requirement**

14. On average, what percentage of load is put on your MEP assets?

____

15. Has transportability of MEP assets been a problem in your unit?

___Agree Strongly ___Agree ___Undecided ___Disagree ___Disagree Strongly

Comments: ____

16. How many trailers does your unit possess? (Specify type of trailer and number)

____

17. Is that number of trailers adequate?

_____ Yes

_____ No. Comments: ____

____

18. Do you feel that your unit's MEP assets are effectively employed?

___Agree Strongly ___Agree ___Undecided ___Disagree ___Disagree Strongly

Comments: ____

____

19. Does your unit get adequate MEP support from combat service support elements?

___Agree Strongly ___Agree ___Undecided ___Disagree ___Disagree Strongly

Comments: ____

____

20. Are additional MEP assets available in a timely manner?

___Agree Strongly ___Agree ___Undecided ___Disagree ___Disagree Strongly

Comments: ____

____

21. Does your unit fully exploit its own resources before drawing on combat service support MEP assets?

___Agree Strongly ___Agree ___Undecided ___Disagree ___Disagree Strongly

Comments: ____

22. Is the procedure used to obtain additional MEP support understandable?

___Agree Strongly ___Agree ___Undecided ___Disagree ___Disagree Strongly

Comments: ____

____

23. Do you have any concerns or experiences from operational exercises or from Southwest Asia concerning MEP requirements and the current MEP program?

____

____

APPENDIX C

MOBILE ELECTRIC POWER STUDY DATA COLLECTION

Level II Holder Survey

The following survey is part of the Mobile Electric Power (MEP) study currently being conducted by the Marine Corps. Your answers to these questions will be analyzed to help the Marine Corps determine its mobile electric power requirements for the future. At any time, please feel free to write in any additional comments appropriate for a given question.

Privacy Act Information

The data collected with this questionnaire will be used for research purposes only. Personal information will be used for administrative and statistical control purposes only. Full confidentiality of your responses will be maintained in the processing of the data. Disclosure of information is voluntary. Not providing information, however, will mean your views will not be included in the analysis of survey results.

Administrative Information (Please Print)

NAME ______________________________

RANK ____________

MOS ____________

UNIT ______________________________

AUTOVON ______________________________

Level II Holder Questions

1. Are you familiar with the level holder concept for Mobile Electric Power?

_____ Yes

_____ No

2. Does your unit have an SOP for Mobile Electric Power or other instructional guidelines?

_____ Yes

_____ No

3. As a level II holder, who you support for mobile electric power?

____

____

____

4. Do you know what their power requirements are?

_____ Yes

_____ No. Comments: ____________________________________

____

____

5. Do you currently have adequate Mobile Electric Power assets to meet their electrical demand?

_____ Yes

_____ No. Comments: ____

____

____

6. Included with this survey is a T/E displaying your unit's power consuming equipment based on the most current information in the LMIS system. To the best of your knowledge, is this T/E complete?

_____ Yes

_____ No: Please make additions or corrections to the T/E

7. How many generators does your unit hold? (Fill in appropriate number in spaces below. This is actual number on hand vice T/O)

_____ 3Kw/60Hz	_____ 10Kw/60Hz	_____ 10Kw/400Hz
_____ 30Kw/60Hz	_____ 30Kw/400Hz	_____ 60Kw/60Hz
_____ 60Kw/400Hz	_____ 100Kw/60Hz	

8. Do you know which generators belong to your unit and those which are intended to support other units?

_____ Yes

_____ No

9. How many of the following types of personnel are in your unit?

_____ Utilities Officer (MOS 1120)

_____ Utilities Chief (MOS 1169)

_____ Electrician (MOS 1141)

_____ Electrical Equipment Repairman (MOS 1142)

10. Does the number of personnel above adequately support continuous operations of your unit's MEP assets?

_____ Yes

_____ No. Comments: ______________________________________

____

____

11. Does the number of personnel above adequately cover continuous operations of the units you support?

_____ Yes

_____ No. Comments: ______________________________________

____

____

12. When your unit deploys, how many sites will your unit divide into on average? (Define a site to be a collection of equipment and personnel getting their power from a single generator) An example would be if a unit divides into a headquarters, operations, and maintenance sites.

No. of sites _____

13. Has the number of sites ever been limited by your power assets?

_____ Yes

_____ No

14. How do you determine the type of generator you need for a given site?

____

____

____

15. Who determines the type and number of generators required for these sites?

____

16. When a unit requires MEP support, how do you determine the correct quantity and type of generator to support that unit?

____

____

17. Do you employ an MOS 1120 (Utilities Officer) or MOS 1169 (Utilities Chief) in your field planning for electrical distributions?

_____ Yes

_____ No

18. On your unit's T/E, annotate next to a given piece of power consuming equipment what you consider it's power requirement to be. Use the following abbreviations;

MC: **Mission Essential Continuous Power. Equipment will operate 24 hours continously and requires 100% assurance that power will be available. (Examples: a radio, radar set, or combat operations center)**

MI: **Mission Essential Intermittent Power. Equipment will operate up to 14.4 hours in a 24 hour period and requires 95% assurance that power will be available. (Example: A maintenance activity such as an electronic maintenance shelter)**

DH: **Deferable Power (High Activity). Equipment will operate up to 9.6 hours in a 24 hour period and requires 75% assurance that power will be available.**

DM: **Deferable Power (Medium Activity). Equipment will operate up to 4 hours in a 24 hour period and requires 50% assurance that power will be available. (Examples: hand tools, test equipment)**

DL: **Deferable Power (Low Activity). Equipment will operate up to 1.2 hours in a 24 hour period and requires only 5% assurance that power will be available. (Example: A coffee pot)**

B: **Battery powered**

V: **Powered by a vehicle power source**

X: **External or other power requirement**

19. On average, what percentage of load is put on your MEP assets?

____

20. What guidelines do you use to determine the type and quantity of generators to have as backup?

____

____

21. Is this backup adequate?

_____ Yes

_____ No. Comments: ______________________________

____

____

22. Has transportability of MEP assets been a problem for your unit?

___Agree Strongly ___Agree ___Undecided ___Disagree ___Disagree Strongly

Comments: ____________________________________

____

23. How many trailers does your unit possess? (Specify by type of trailer and number)

____

24. Is that number of trailers adequate?

_____ Yes

_____ No. Comments: ____

____

____

25. Do you feel that your unit's MEP assets are effectively employed?

___Agree Strongly ___Agree ___Undecided ___Disagree ___Disagree Strongly

Comments: ____

____

____

26. Are additional MEP assets available in a timely manner for units requiring support?

___Agree Strongly ___Agree ___Undecided ___Disagree ___Disagree Strongly

Comments: ____

____

____

27. Do supported units fully exploit their own resources before drawing on combat service support MEP assets?

___Agree Strongly ___Agree ___Undecided ___Disagree ___Disagree Strongly

Comments: ____

____

____

28. Is the procedure used to obtain additional MEP support understandable by the units you support?

___Agree Strongly ___Agree ___Undecided ___Disagree ___Disagree Strongly

Comments: ____

____

____

29. Do you have any concerns, experiences, or lessons learned from operational exercises or from Southwest Asia concerning MEP requirements and the current MEP program?

____

____

APPENDIX D

```
$TITLE  MOBILE ELECTRIC POWER (MEP) MODEL
$offupper offsymxref offsymlist offuellist inlinecom { }
$ontext

    By:      David W. Samples, Captain, USMC
    Date:    6 August 1992/2045
    Source:  MAGTF Warfighting Center and Marine Corps Systems Command
             Quantico, Virginia

    Modified: Richard E. Rosenthal, Naval Postgraduate School
              408-646-2795  (1 July 92)

    Description:

         This model helps to determine what type and quantity of
    Mobile Electric Power (MEP) generators to purchase during a given
    acquisition year.  It also helps to optimize the distribution of
    the new generators and existing inventory among units to best meet
    the power requirements of the force.

         Inputs from the Belvoir Generator Allocation Program (BGAP)
    are used to help determine the most accurate power requirement for
    each individual Marine Corps unit while the GAMS model helps to
    fit total Marine Corps assets among all units.

$offtext

options
    limrow    =      0
    limcol    =      0
    solprint  =    off
    lp        =     xa
    iterlim   = 100000
    reslim    =   5000
    ;


SETS
    T  fiscal year acquisition period        /1992*2000/
    M  type of standard DOD MEP generator    /M016, M003, M112, M005,
                                              M114, M006, M115, M007 /
    P  penalty for BGAP deviation            /UP, DOWN/
    ;


SET I type of Marine Corps unit /
$INCLUDE UNITS3.PRN
/ ;

SET DEPOT(I) those units in set i which are depot units /DEPOT/ ;

ALIAS (I,II), (M,MM), (T,TT) ;
```

```
*the following include statements contain all the program tabular data
$INCLUDE FORCES3.PRN       {table forces(i,t)}
$INCLUDE INITINV3.PRN      {table initinv(i,m)}
$INCLUDE BGAP3.PRN         {table bgap(i,m,t)}
$INCLUDE NEWCOST3.PRN      {table newcost(m,t)}
$INCLUDE SUBCOST3.PRN      {table subcost(m,mm)}
$INCLUDE PENALTY3.PRN      {table penalty(m,p)}
$INCLUDE SUBST3.PRN        {table subst(m,mm)}


PARAMETER
* excess inventory allowed
    THRESHOLD(I) maximum permissible excess inventory in % over BGAP ;

        THRESHOLD(I) = .25 ;


PARAMETER
* generator demand by unit
    DEM(I,M,T)  Demand of unit i for generator type m in period t ;

        DEM(I,M,T) =  BGAP(I,M,T) * FORCES(I,T) ;


PARAMETER
* budget information
    BUDGET(T) amount of funds available in year t to purchase
*             new generators (in thousands of dollars)

       /1992  500
        1993  500
        1994  500
        1995  500
        1996  500
        1997  500
        1998  500
        1999  500
        2000  500 /
        ;


PARAMETER
* retirement percentages
    RETPCT(M) percentage of mep generator type m retired each year

       /M016  0
        M003  0
        M112  0
        M005  0
        M114  0
        M006  0
        M115  0
        M007  0 /
        ;

PARAMETER
* maximum demands
    MAXDEM(M,T) largest unit demand for m in t ;

        MAXDEM(M,T)  =  SMAX( I, DEM(I,M,T) )  ;
        MAXDEM(M,T) $ (MAXDEM(M,T) EQ 0)  =  1 ;
```

```
PARAMETERS
* penalties for inventory deviations

    UPPEN(I,M,T) penalty for gens in inventory over  BGAP recommendation
    DNPEN(I,M,T) penalty for gens in inventory under BGAP recommendation ;

    {Adjust penalty for size of demand and time discounting.  Depot does
     not incur penalty for holding inventory}

        UPPEN(I,M,T)  = PENALTY(M,"UP")  *  .99**(ORD(T)-1)
                        * exp( - DEM(I,M,T)  / MAXDEM(M,T) ) ;

        UPPEN("DEPOT",M,T)  = 0 ;

        DNPEN(I,M,T) $ DEM(I,M,T)  = PENALTY(M,"DOWN")  *  .99**(ORD(T)-1)
                        * exp( - DEM(I,M,T)  / MAXDEM(M,T) ) ;


PARAMETER
*transfer cost

    XFERCOST(M) cost of tranferring generator between unit i and depot

       /M016  1.0
        M003  2.0
        M112  2.0
        M005  3.0
        M114  3.0
        M006  4.0
        M115  4.0
        M007  5.0 /
        ;

SCALARS
    WTSUB     weighted penalty for substitution of generators     /.1 /
    WTXFER    weighted penalty for transferring of generators     /.03/
    WTUP      weighted penalty for inventory over BGAP recommend  /.2 /
    WTDOWN    weighted penalty for inventory under BGAP recommend / 4 /
    LEAD      num years of pre-purchase and stockpiling allowed   / 1 /
    ;

SET Q(I,M,T)  unit i qualified to maintain generator m in time t ;

    Q(I,M,T)   =  YES $ ( FORCES(I,T) AND
                  SMAX( TT $ ( ( ORD(TT) GE ORD(T) )   AND
                               ( ORD(TT) LE ORD(T) + LEAD ) ),
                                 DEM(I,M,TT) ) ) ;

POSITIVE VARIABLES
    X(I,M,T) acquisition of type m generator by unit i in period t
    Y(I,M,MM,T) num of mm gens used to fill demand for m gen by i in t
    TRANS(I,II,M,T) transfers of type m generators from i to ii in t
    STOCKPILE(I,M,T) elastic variable for inventory over BGAP
    EDN(I,M,T) elastic variable for inventory under BGAP
    ;

FREE VARIABLE
    PENTOT  total penalty for all USMC units ;
```

```
*Variable considerations
{1. Do not allow too much overinventory.  If a unit's inventory reaches the
     overinventory threshold, the unit will send excess generators to depot.
 2. If the unit ceases to exist, all inventory is sent to depot.}
    STOCKPILE.UP(I,M,T) $ ( Q(I,M,T) $ ( NOT DEPOT(I) ) )
               =  MAX ( CEIL( THRESHOLD(I) * DEM(I,M,T) ),
                  SMAX( TT $ ( ( ORD(TT) GT ORD(T) )  AND
                               ( ORD(TT) LE ORD(T) + LEAD ) ),
                                 DEM(I,M,TT) - DEM(I,M,T) ) ) ;
    STOCKPILE.UP(I,M,T) $ ( (NOT Q(I,M,T)) $ ( NOT DEPOT(I) ) )  =  0 ;

EQUATIONS
    BALANCE(I,M,T)    inventory from previous year plus purchase plus
*                     transfer in equals transfer out plus retire plus
*                     inventory at end-of-year
    MONEY(T)          dollars spent in period t less or equal amount avail
    DEMAND(I,M,T)     generator demand of type m for unit i in period t
    PENALIZE          total force deviation from BGAP recommendations
    ;


BALANCE(I,M,T) ..

* Uses of Generators:

    TRANS(I,"DEPOT",M,T) $ (NOT DEPOT(I))
                             {transfers out of i if not depot}

+   SUM( II $ Q(II,M,T), TRANS(I,II,M,T)) $ DEPOT(I)
                             {transfers out of i if i=depot}

+   SUM( MM $( SUBST(MM,M) * BGAP(I,MM,T) * FORCES(I,T)), Y(I,MM,M,T) )
                             {type m generators used to meet type mm demand}

+   STOCKPILE(I,M,T) $ STOCKPILE.UP(I,M,T)
                             {excess inventory stockpiled for next period}

=E=

* Sources of Generators:

    INITINV(I,M) $ (ORD(T) EQ 1)  {initial inventory}


+   X(I,M,T) $ Q(I,M,T)           {purchases for qualified units}


+   TRANS("DEPOT",I,M,T) $ ( (NOT DEPOT(I)) $ Q(I,M,T) )
                                  {transfers into i if i is not depot}

+   SUM( II $( NOT DEPOT(II)), TRANS(II,I,M,T)) $ DEPOT(I)
                                  {transfers into i if i=depot}

+   (1-RETPCT(M)) *
    SUM( MM $( SUBST(MM,M) * DEM(I,MM,T-1) ), Y(I,MM,M,T-1) )
                          {type m generators used last period less attrition}

+   (1 - 0.5 * RETPCT(M)) * STOCKPILE(I,M,T-1) $ STOCKPILE.UP(I,M,T-1)
                          {stockpiled generators from last period attrite but at
                           a slower rate than generators in regular use}
;
```

```
DEMAND(I,M,T) $ DEM(I,M,T) .. {Demand constraint exists iff demand exists}


    SUM(MM $ SUBST(M,MM), Y(I,M,MM,T)) {number of type mm generators
                                        filling generator type m demand}

+   EDN(I,M,T)                  {elastic variable for shortage under demand}

=E=

    DEM(I,M,T)                  {BGAP recommended generators}
;


MONEY(T) ..

    SUM( (I,M) $ Q(I,M,T), X(I,M,T) * NEWCOST(M,T) * FORCES(I,T) )
                                {sum of all gens purchased for all units}

=L=

    BUDGET(T)                   {amount available for new generator purchase}
;

PENALIZE ..
    WTSUB * SUM( (I,M,MM,T) $ ( SUBST(M,MM) * DEM(I,M,T) ),
                 SUBCOST(M,MM) * Y(I,M,MM,T) )
                                {weighted penalty for using a larger
                                 capacity generator than necessary}

+   WTXFER * SUM( (I,M,T) $ (NOT DEPOT(I)), XFERCOST(M)*
                                (TRANS(I,"DEPOT",M,T) + TRANS("DEPOT",I,M,T) ) )
                                {weighted penalty for transferring a generator
                                 between a unit and the depot}

+   WTUP * SUM((I,M,T) $ Q(I,M,T), UPPEN(I,M,T) * STOCKPILE(I,M,T) )
                                {weighted penalty for holding inventory
                                 over the BGAP recommendation}

+   WTDOWN * SUM( (I,M,T) $ DEM(I,M,T), DNPEN(I,M,T) * EDN(I,M,T) )
                                {weighted penalty for holding inventory
                                 under the amount recommended by BGAP}
=E=

    PENTOT
;

MODEL MEPTEST /ALL/ ;
SOLVE MEPTEST USING LP MINIMIZING PENTOT ;
```

INITIAL DISTRIBUTION LIST

		No. Copies
1.	Defense Technical Information Center Cameron Station Alexandria, VA. 22304-6145	2
2.	Library, Code 52 Naval Postgraduate School Monterey, CA. 93943-5002	2
3.	Commandant of the Marine Corps Code TE 06 Headquarters, U.S. Marine Corps Washington, D.C. 20380-0001	1
4.	Chairman Operations Research Department, Code OR-PD Naval Postgraduate School Monterey, CA. 93943-5004	1
5.	Operations Research Department, Code OR-KE Attn: Professor William G. Kemple Naval Postgraduate School Monterey, CA. 93943-5004	1
6.	Operations Research Department, Code OR-RL Attn: Professor Richard E. Rosenthal Naval Postgraduate School Monterey, CA. 93943-5004	2
7.	Mr. Dick Voltz Studies and Analysis Division (Code WF13) MCCDC Quantico, VA. 22134	1
8.	Captain David W. Samples, USMC Studies and Analysis Division (Code WF13) MCCDC Quantico, VA. 22134	1
9.	Major R.A. Kelish, PM Engineers Marine Corps Systems Command Quantico, VA. 22134	1

10. Captain P. Mack, USMC 1
Requirements Division (Code WF11D), MCCDC
Quantico, VA. 22134

11. James P. Lucas (Code SATBE-FEA) 1
Belvoir R,D & E
Fort Belvoir, VA. 22060-5606

Thesis
S1556 Samples
c.1 United States Marine
Corps Mobile Electric
Power Optimization Model.